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CRUSTAL MOVEMENT

in the

Lake Ontario-Upper St. Lawrence River Basin

by

CHARLES A. PRICE
CANADIAN HYDROGRAPHIC SERVICE

CANADA

SURVEYS AND MAPPING BRANCH

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PREFACE

Since 1912 the Canadian Hydrographic Service has precisely recorded the water levels of the Great Lakes and St. Lawrence River and coordinated similar data covering the past 100 years. Early analyses showed progressively increasing differences between recorded water levels at various locations. Several studies have been made to establish the rate and direction of these phenomena, which are attributed to tilting of the earth's crust. This comprehensive report on crustal movement in the Lake Ontario region is part of an intensive study covering all of the Great Lakes.

F. C. G. Smith,
Dominion Hydrographer.

TABLE OF CONTENTS

CRUSTAL MOVEMENT

IN THE

LAKE ONTARIO-UPPER ST. LAWRENCE RIVER BASIN

INTRODUCTORY

1 - In connection with hydrologic studies of the Great Lakes-St. Lawrence Waterway the Canadian Hydrographic Service, which is responsible for precisely recording the levels of this waterway, has under way an intensive study of the present crustal movement in all the Great Lakes basins. The purpose of this preliminary report, restricted to the Lake Ontario-Upper St. Lawrence River Basin, is to assess the direction and rate of the present differential movement, which has a direct bearing on hydraulic studies and problems pertaining to Lake Ontario, and to pending developments in the International Rapids section of the St. Lawrence River.

GEOLOGICAL EVIDENCE

2 - It is a geological fact that for thousands of years there has been a more or less continuous differential uplifting of the earth's crust in the Lake Ontario Basin. It is considered by most authorities that this crustal movement is due to forces which tend to restore the isostatic equilibrium greatly disturbed during the growth and retreat of the glacier, which during the Ice Age, covered Eastern North America. The ice sheet was thousands of feet thick at its centre in the Province of Quebec (1), and for thousands of years the Lake Ontario Basin was covered with ice which extended a hundred miles into the State of New York (2).

3 - When the glacier receded northward from the Ontario Basin, Lake Iroquois was formed, held up by the front of an ice sheet, which during the life of Lake Iroquois blocked the St. Lawrence valley as an outlet to the sea (3). Consequently the waters of Lake Iroquois discharged through an outlet at Rome, N.Y., into the Mohawk valley, which leads to the Hudson and thence to the sea (4).

4 - When the ice sheet retreated from the St. Lawrence valley, Lake Iroquois waters escaped through that new and lower outlet (5). The lake elevation fell below the levels previously maintained by the Rome outlet weir, and its shoreline beaches have since remained higher than any subsequent water levels within its perimeter, as evidence of Lake Iroquois' existence and dimensions.

5 - Lake Iroquois beaches when formed must have been on level planes contemporary with the various stages of the lake during the periods of beach formation. These beaches are now differentially uplifted northeasterly from their present level at Hamilton, Ontario, to relative maximum uplifts of well over 300 feet at "Pancake Hill" (H on Plate 0-1), near West Huntingdon, Ontario, and at a location (10 on Plate 0-1), near Watertown, N.Y. (6). The general direction of the slope resulting from the differential uplift which raised the shores of Lake Iroquois is considered to have been N. 20^{o} E. (7).

6 - Locations in respect to the perimeter of Lake Ontario (8), at which Lake Iroquois beaches have been identified are shown on Plate 0-1, with relative elevations of the highest beaches in feet (9), and with distances in miles from a base line N. 70^{o} W. through the westerly end of Lake Iroquois, at Hamilton, Ontario. These relative differential uplifts by crustal movement since the birth of Lake Iroquois are shown graphically on Plate 0-2, with the locations north of Lake Ontario alphabetically designated and those south of Lake Ontario numerically designated.

7 - Geological data indicates that at one stage during the period of the draining of Lake Iroquois and of the birth of Lake Ontario, the water level in their common basin was very little, if any, higher than sea level (10), which extended into the St. Lawrence valley at least as far as Brockville, Ontario (11). Subsequent crustal movement must have raised the St. Lawrence weir from about sea level of that time, to its present elevation of well over 200 feet. The water level of Lake Ontario must also have progressively raised since its birth relative to the uplifting St. Lawrence weir with the lake perimeter correspondingly expanding to its present dimensions.

Reference 1 to 7 and 10, pages 30-32; 8 and 9, map 45f, A.P. Coleman, "Lake Iroquois", Ontario Department of Mines, Vol. XIV, Part VII, 1936.

Reference 11, Figure 14, page 272, R.J. Lougee, "A Chronology of Postglacial Time in Eastern North America". The Scientific Monthly, Vol. LXXVI, No. 5, May 1953.

WATER LEVELS AND GAUGE RELATIONS

8 - Since 1860 the long term records of Lake Ontario water levels are those recorded at Port Dalhousie, Toronto, Oswego, Kingston, and Cape Vincent, for the periods of years indicated on Figures and Plates attached hereto.

9 - Previous to 1900 the records on the whole are good, but overall gauge relations indicate that at various times the zeros of some of the gauges must have been in error for varying periods, relative to their standard references.

10 - Since 1900 the accuracy of records has progressively improved, until with the advent of hourly readings from self-registering gauge records, such data can be termed precise.

11 - The original records have been used in this study, without adjustments or corrections for apparent errors in the older records.

12 - For gauge relations the mean value of the four months, June to September, has been used for each year. This eliminates possible discrepancies arising from the use of daily staff gauge readings taken during winter, ice, flood, spring and autumn gale conditions, etc.

13 - The records for each of the five locations referred to in Paragraph 8 are referenced to locally stable bench marks and, since the surface of Lake Ontario is a level plane, gauge relations between locations should remain constant. However inter-location gauge relations have been progressively departing from constant during the full period of records, except that the relation between Kingston and Cape Vincent has continued to be more or less constant. Therefore it is evident that there must still be progressive differential uplifting of the earth's crust in the Lake Ontario-Upper St. Lawrence River Basin, due to continuing postglacial crustal movement.

14 - Figures 0-1 to 0-5 inclusive, show the year-to-year gauge relations since 1860 with each location, in its turn, considered as constant.

15 - Figures 0-6 to 0-10 inclusive show five year moving mean gauge relations since 1860 with each location, in its turn, considered as constant. This treatment balances minor year-to-year discrepancies and provides more consistent overall curves.

16 - Plate 0-3 shows the year-to-year gauge relations of each location since 1860 to the mean value of all locations.

17 - Plate 0-4 shows five year moving mean gauge relations of each location since 1860 to five year moving mean values of all locations. This method of procedure appears to provide the simplest and clearest means of presenting the inter-locking gauge relations for the five locations.

18 - Plate 0-5 shows ten year mean gauge relations of each location since 1860 to ten year mean values of all locations.

19 - Plate 0-6 shows the present rate of change in gauge relation at each location from the mean value of all locations. The axes, or points of balance between each pair of locations, are computed on a mileage-rate basis. The common axis line runs N. 50° W. so that the present overall direction of changing gauge relations is N. 40° E. This defines the present direction and rate of change in slope due to crustal uplift, but does not establish the zero line or hinge of least differential uplift.

20 - Geological facts provide indisputable evidence that for thousands of years there has been a differential uplifting of the earth's crust in a north-easterly direction, from at least as far west as the westerly end of glacial Lake Iroquois. Therefore on Plate 0-7 a base line has been drawn at N. 50° W. through Port Dalhousie, the most westerly of the five gauge locations. This is the same bearing as that established on Plate 0-6, as the present axis of gauge relation balance.

21 - Plate 0-7 shows for each location, the present relative rate of differential uplift by crustal movement from the base line through Port Dalhousie. The relative differential uplifts shown for Lock 27 and Cornwall have been computed by projection.

22 - Plate 0-8 shows graphically the present relative rate per 100 years of differential crustal uplift in the Lake Ontario-Upper St. Lawrence River Basin, from the base line N. 50° W., through Port Dalhousie. The relative differential uplift shown for Lock 27 is also evidenced by change in river slopes from Lake Ontario to Lock 27.

23 - Plate 0-9 shows the rate per 100 years at which the slope of the Niagara River from Lake Erie to Lake Ontario, has decreased since 1860.

24 - Plate 0-10 shows, -(A) The rate per 100 years at which the depth of water over the entrance sill of the drydock at Kingston, Ontario, has increased since 1900;

(B) The rate per 100 years at which the depth of water over the lower entrance sill of the Old Welland Canal, at Port Dalhousie, Ontario, has increased since 1860;

(C) The rate per 100 years at which the depth of water over the upper entrance sill of the Old Welland Canal, at Port Colborne, Ontario, has decreased since 1860.

25 - The facts herewith submitted as evidence of the present direction and rate of relative differential uplifting by crustal movement are all founded on gauge relations and analyses of actual water level data. The rates of change

in all cases are expressed in feet per 100 years. The 100-year lines of interlocking gauge relations are based principally on the precise water level records since 1920. The gauge relations prior to 1920 are shown to illustrate the fact that the trend of changing relations and crustal uplift has been relatively the same since 1860.

CONCLUSIONS

26 - The increasing depth of water over the entrance sills of the drydock at Kingston, and of the canal lock at Port Dalhousie, shown on Plate 0-10, could have been caused if the elevation of the "Galops Weir" at Lock 27 had remained constant, and the drydock and canal sill elevations had subsided. However if the "Galops Weir" had remained constant then the level of Lake Ontario would also have remained constant under the same condition of flow, and could not have contributed to the reduction of the overall slope in the Niagara River as evidenced on Plate 0-9.

27 - The differential uplift per 100 years at the "Galops Weir", shown on Plate 0-8, must have relatively raised the level of Lake Ontario; increased the depth of water over the lower sill of the Old Welland canal; reduced the overall slope of the Niagara River; and increased the depth of water over the drydock sill at Kingston.

28 - The progressively changing gauge relations, the progressively increasing depth of water over the drydock and canal sills, and the progressively decreasing overall slope of the Niagara River, are all inter-related facts which definitely prove that the earth's crust in the Lake Ontario-Upper St. Lawrence River Basin is presently being differentially uplifted at the relative rates per 100 years, shown on Plate 0-7, and listed as follows:-

LOCATIONS		RELATIVE UPLIFT IN FEET PER 100 YEARS
Cornwall,	Ontario	1.29 ±
Lock 27, (Galops Weir)	Ontario	1.10 ±
Kingston,	Ontario	0.76 ±
Cape Vincent,	N.Y.	0.76 ±
Oswego,	N.Y.	0.55 ±
Toronto,	Ontario	0.10 ±
Port Dalhousie,	Ontario	0.00 ±

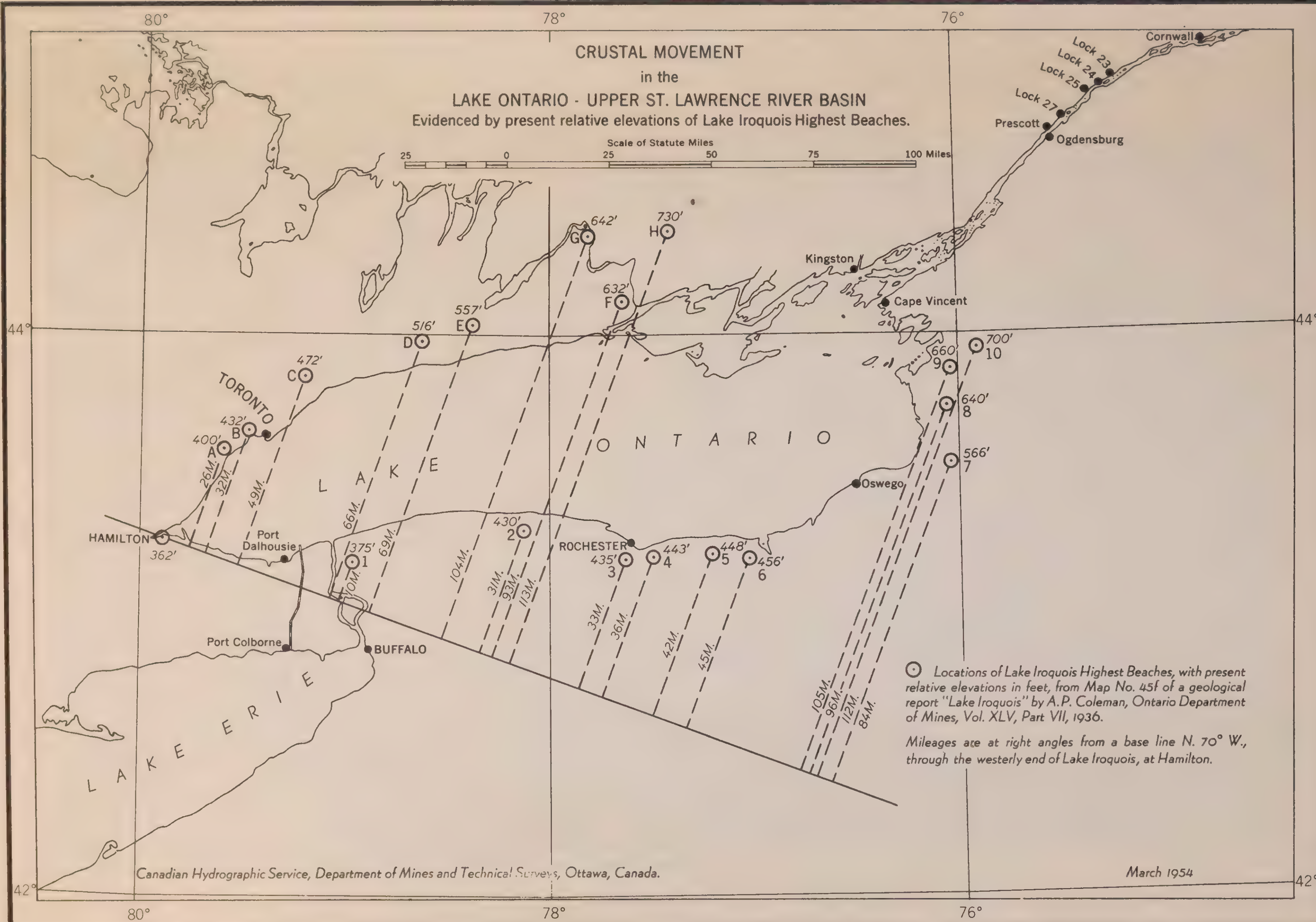
The indicated rate of crustal uplift from Kingston to Cornwall is supported by recent precise levelling.

APPENDICES

Plate No. 0-1

CRUSTAL MOVEMENT in the LAKE ONTARIO - UPPER ST. LAWRENCE RIVER BASIN

Evidenced by present relative elevations of Lake Iroquois Highest Beaches.



Locations of Lake Iroquois Highest Beaches, with present relative elevations in feet, from Map No. 45f of a geological report "Lake Iroquois" by A.P. Coleman, Ontario Department of Mines, Vol. XLV, Part VII, 1936.

Mileages are at right angles from a base line N. 70° W., through the westerly end of Lake Iroquois, at Hamilton.

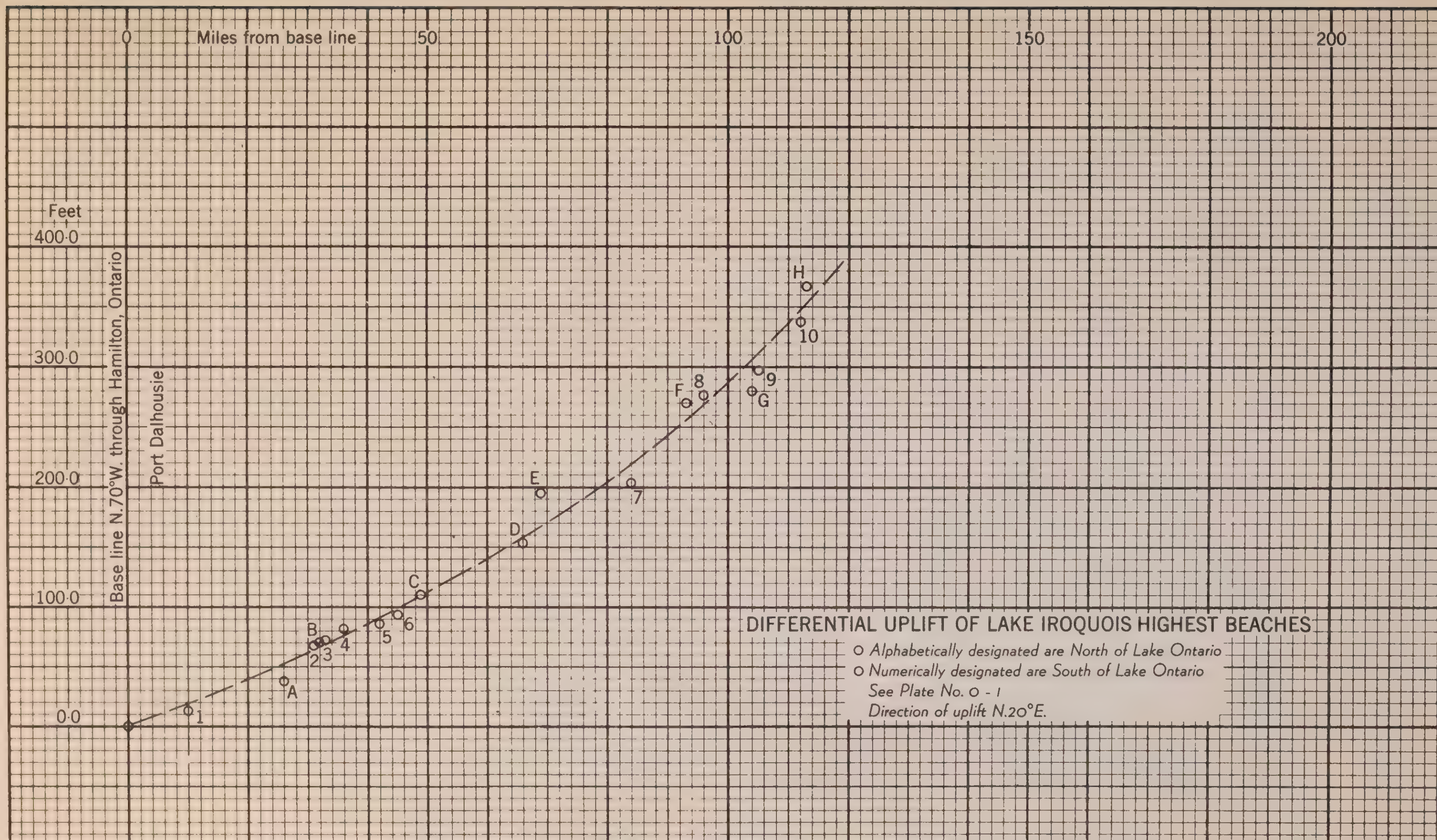
Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.

March 1954

CRUSTAL MOVEMENT

in the

LAKE ONTARIO - UPPER ST. LAWRENCE RIVER BASIN



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada. March 1954

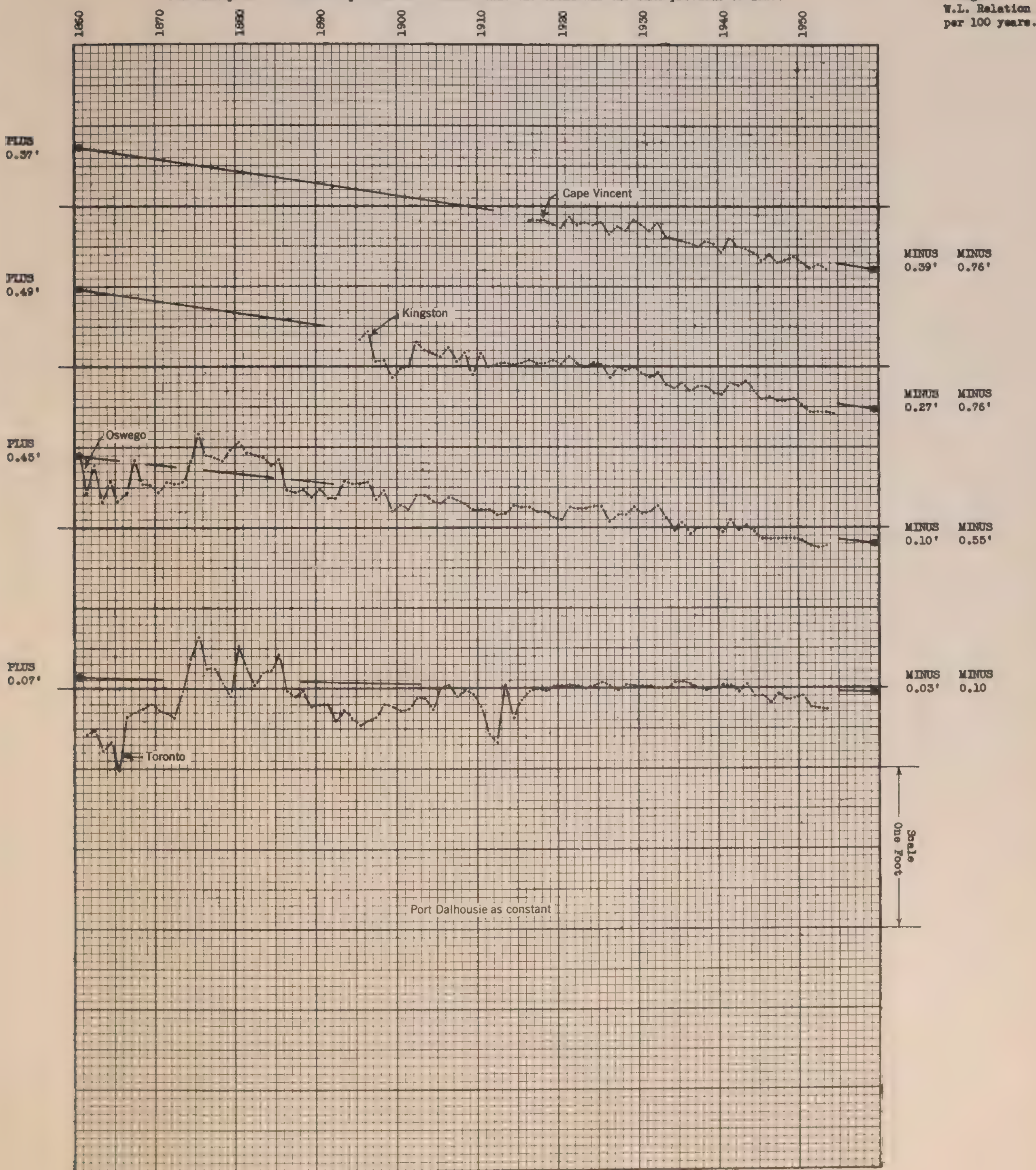
PLATE No. O - 2

LAKE ONTARIO

Recorded mean water surface elevations for June-September of each year, relative to the mean water surface elevations recorded during the same period at Port Dalhousie, Ontario.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919.
The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service. Department of Mines and Technical Surveys, Ottawa, Canada.

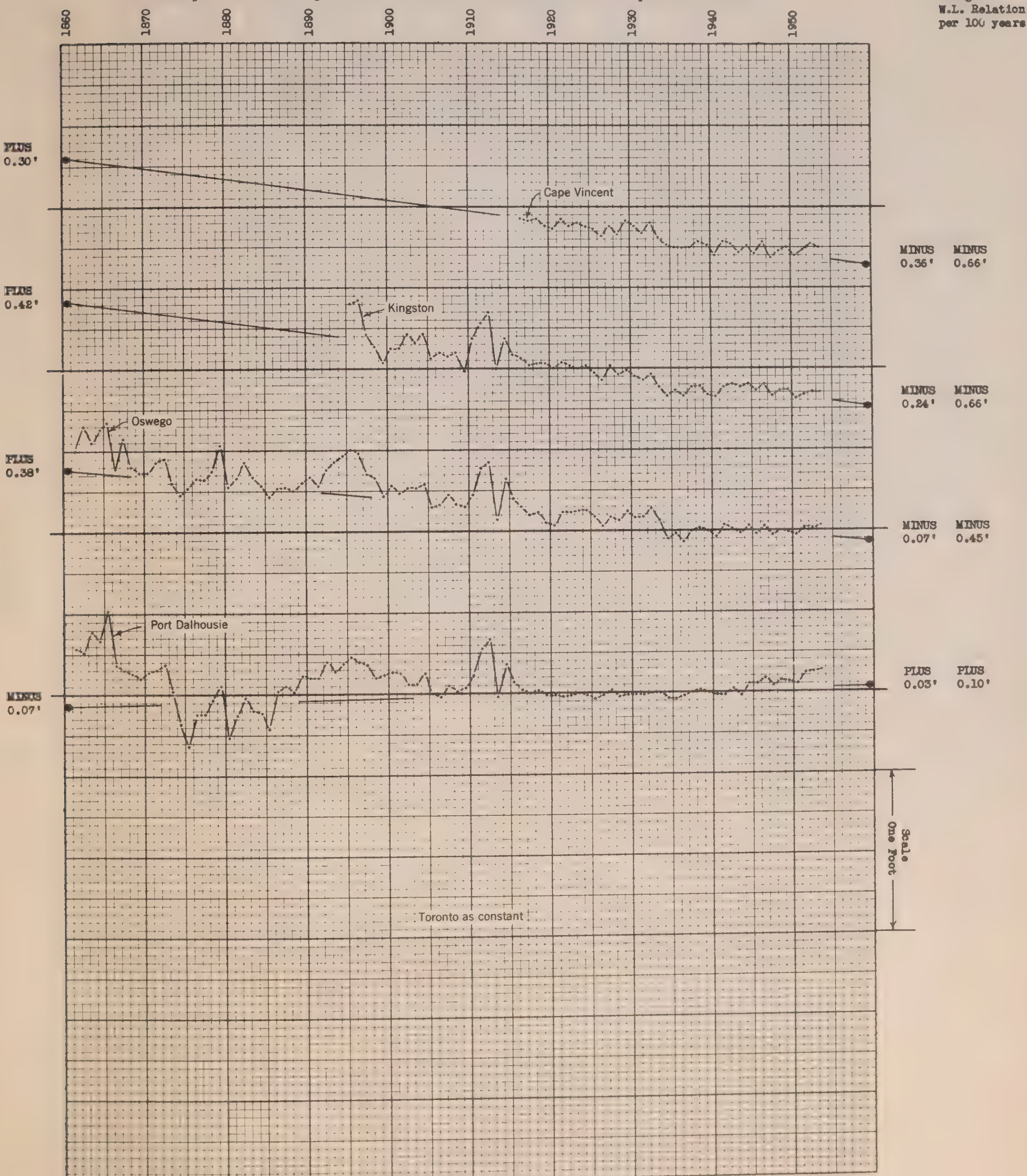
March 1954

LAKE ONTARIO

Recorded mean water surface elevations for June- September of each year, relative to the mean water surface elevations recorded during the same period at Toronto, Ontario.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919.
The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.

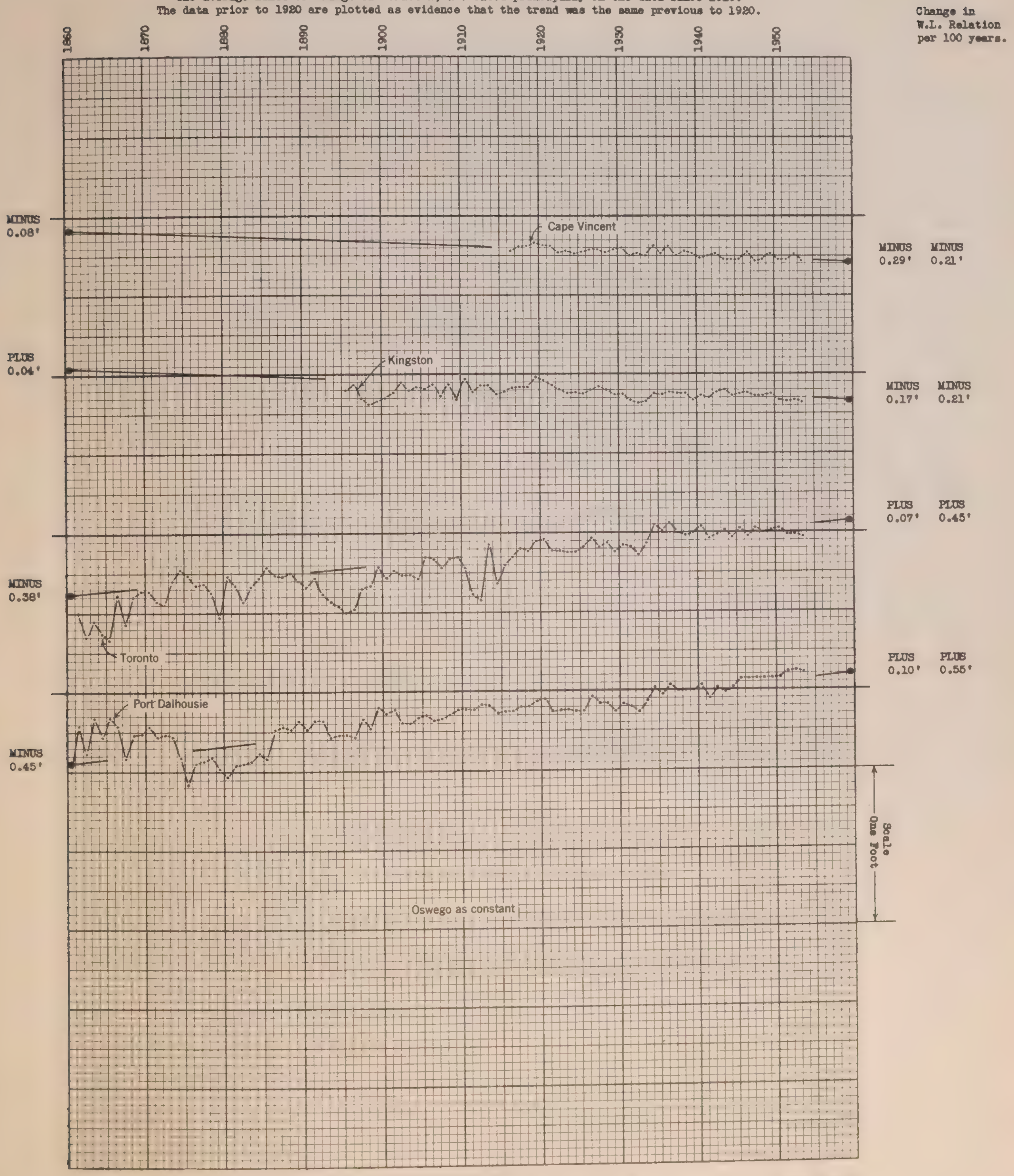
March 1954

LAKE ONTARIO

Recorded mean water surface elevations for June-September of each year, relative to the mean water surface elevations recorded during the same period at Oswego, New York.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919.
The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.

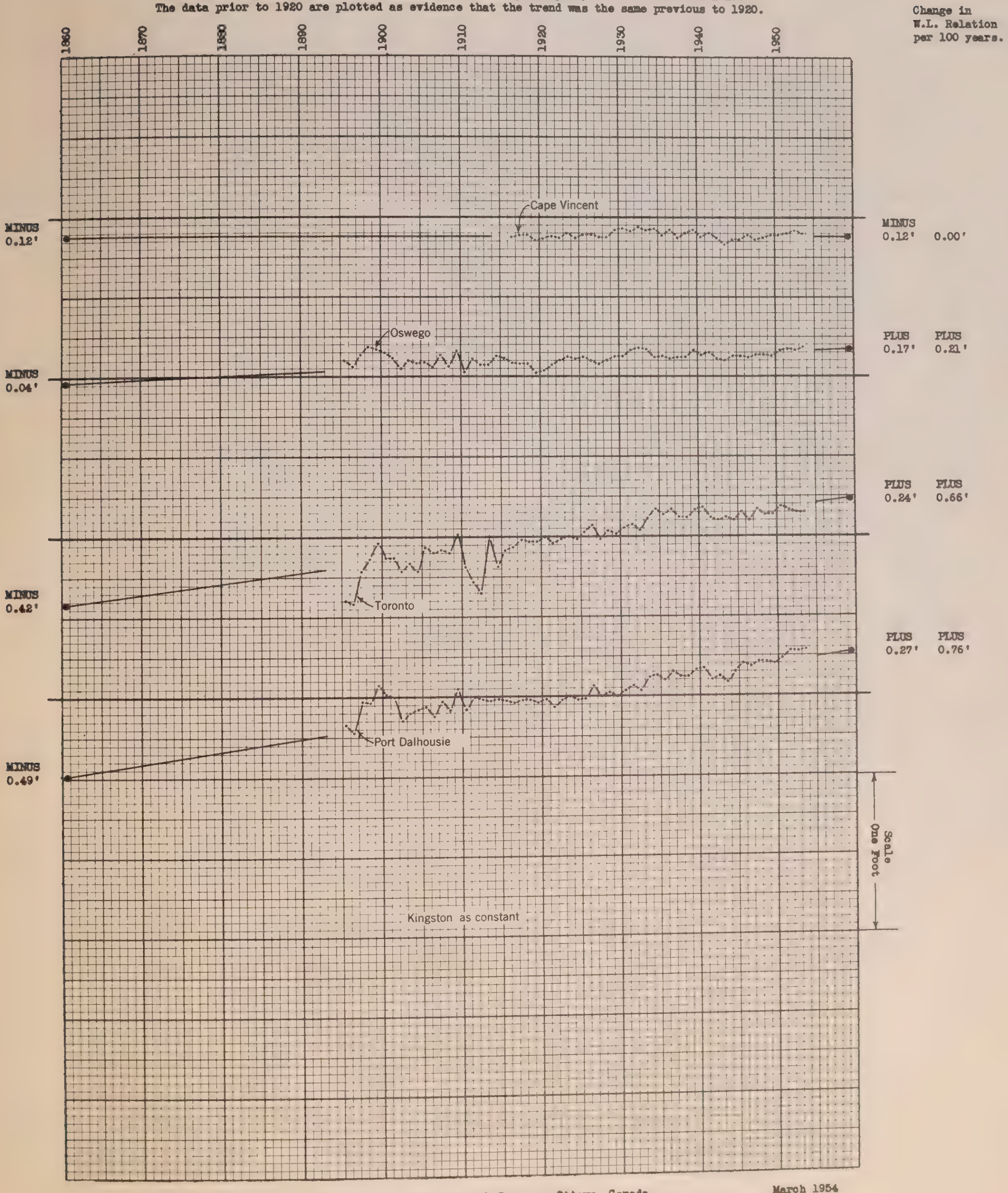
March 1954

LAKE ONTARIO

Recorded mean water surface elevations for June-September of each year, relative to the mean water surface elevations recorded during the same period at Kingston, Ontario.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919. The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.

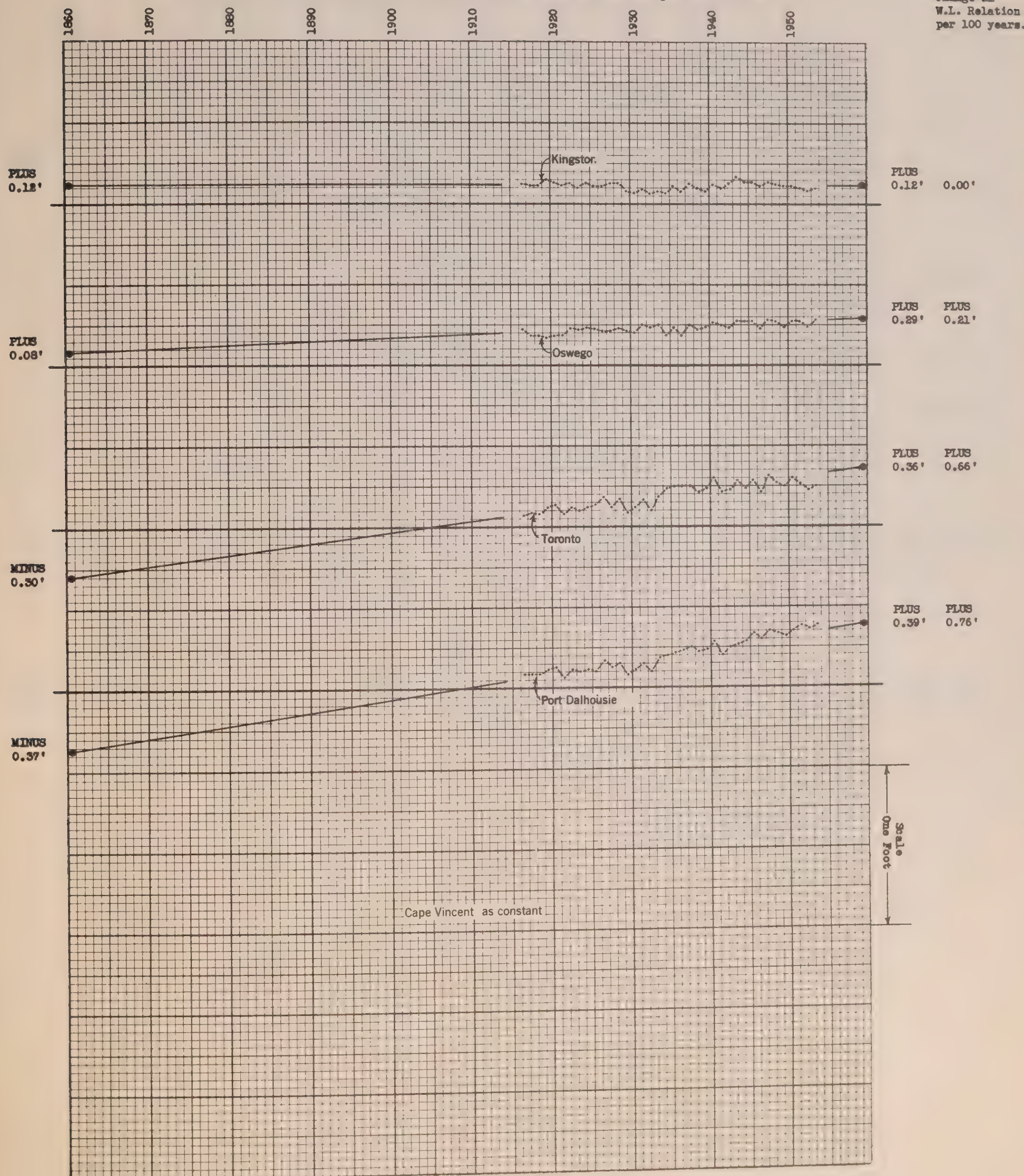
March 1954

LAKE ONTARIO

Recorded mean water surface elevations for June-September of each year, relative to the mean water surface elevations recorded during the same period at Cape Vincent, New York.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919. The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.

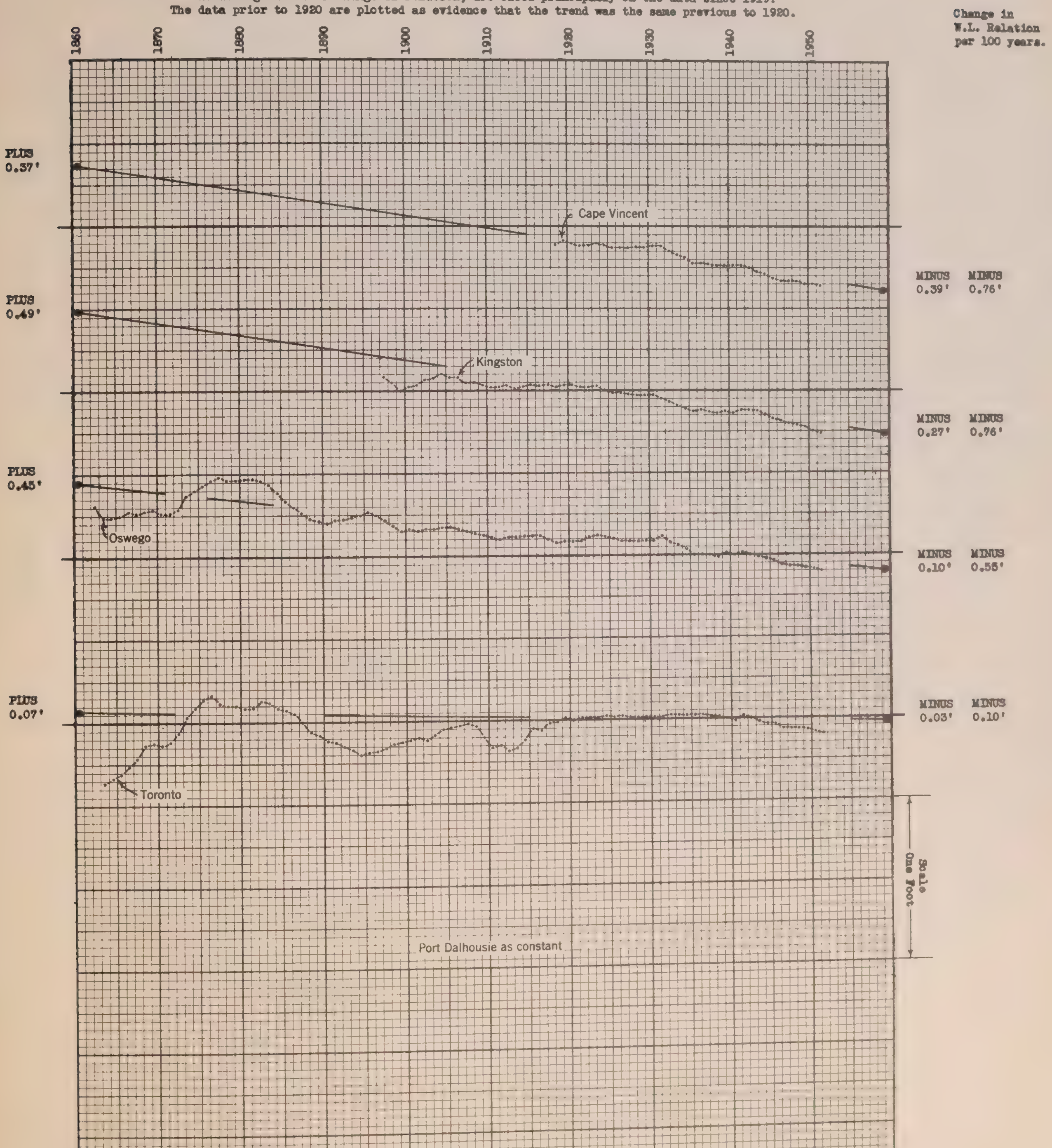
March 1954

LAKE ONTARIO

Moving five year mean water surface elevations for June-September, relative to the moving five year mean water surface elevations during the same period at Port Dalhousie, Ontario.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919. The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.

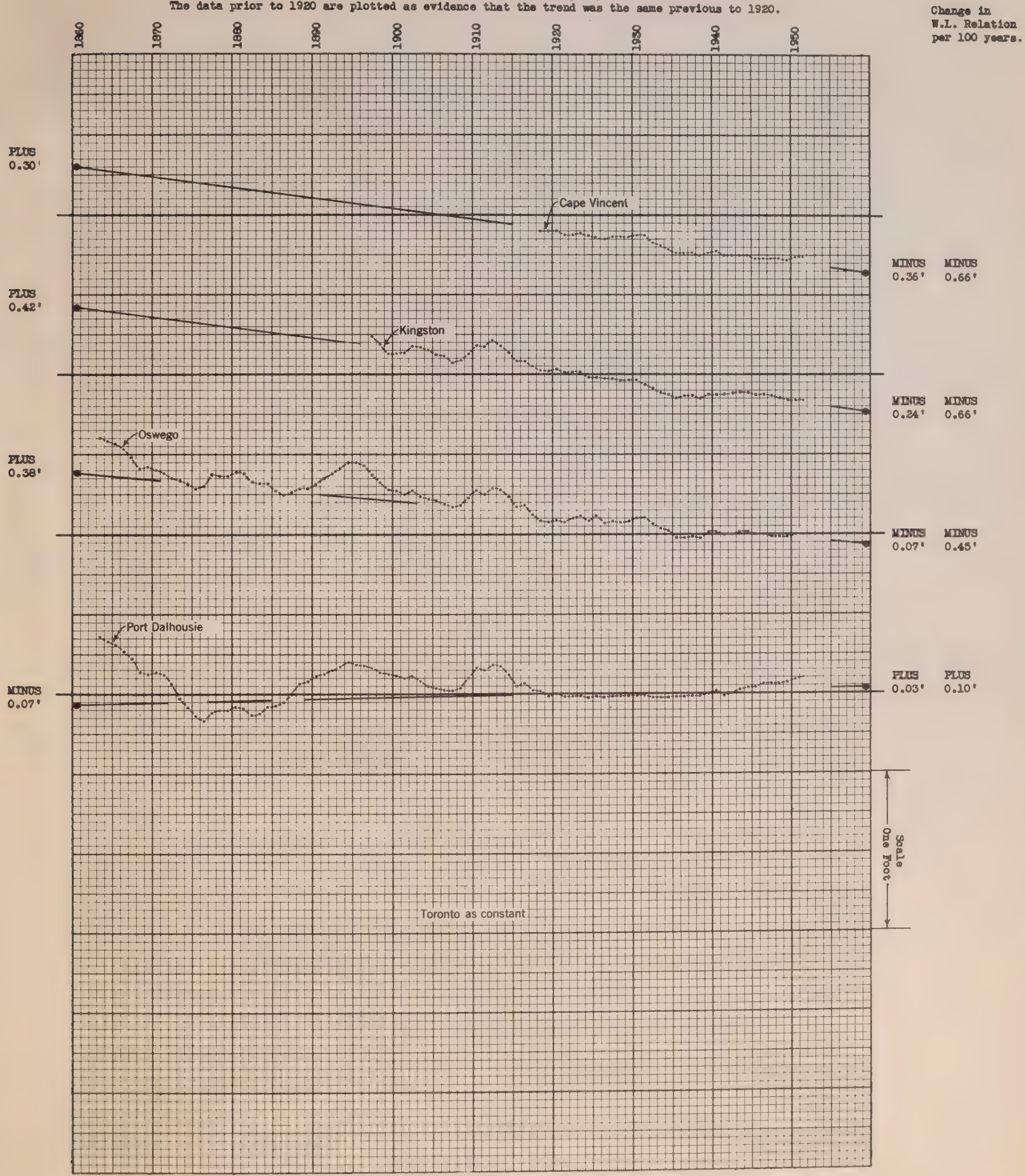
March 1954

LAKE ONTARIO

Moving five year mean water surface elevations for June-September, relative to the moving five year mean water surface elevations during the same period at Toronto, Ontario.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919.
The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



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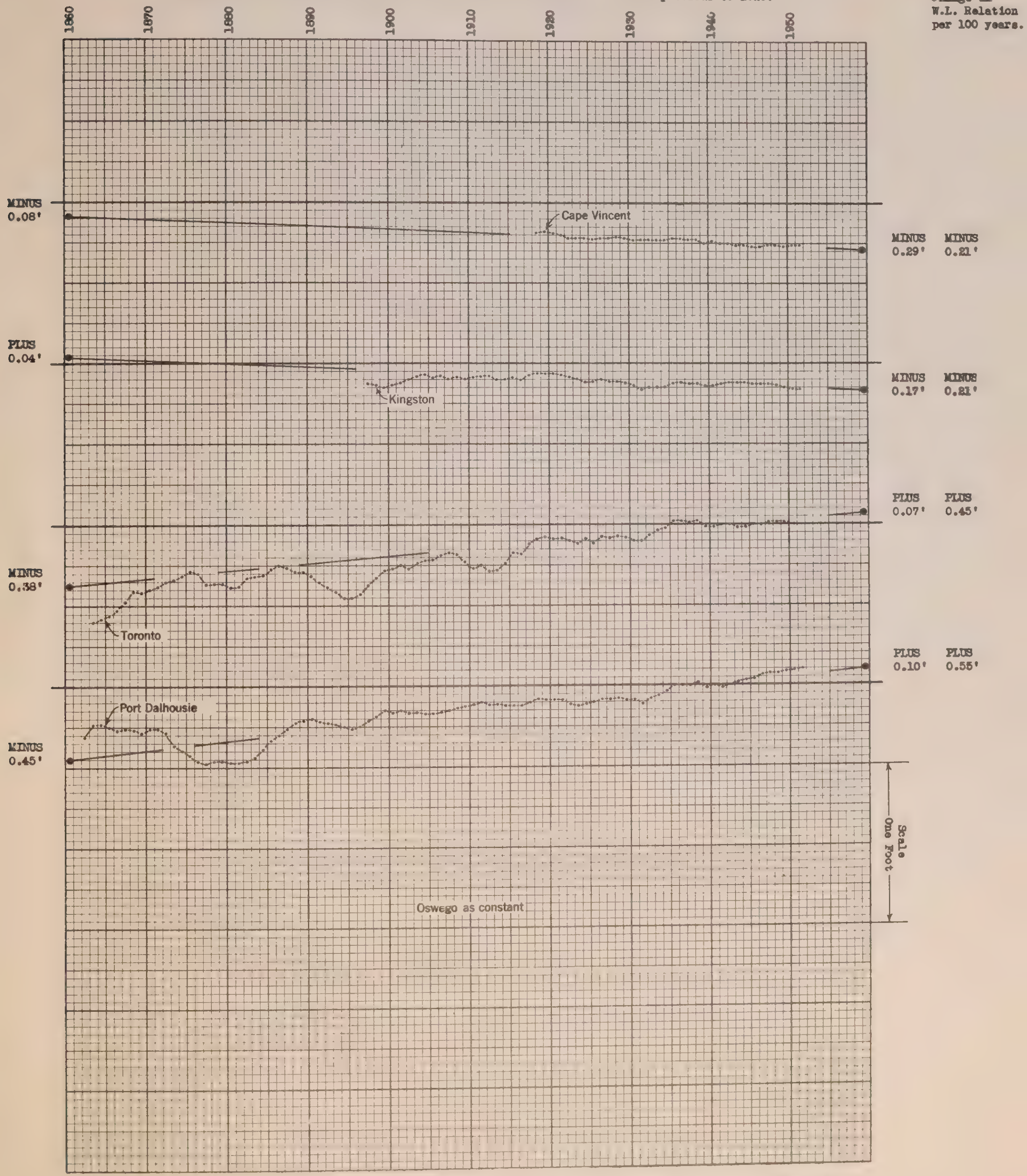
March 1954

LAKE ONTARIO

Moving five year mean water surface elevations for June-September, relative to the moving five year mean water surface elevations during the same period at Oswego, New York.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919.
The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.

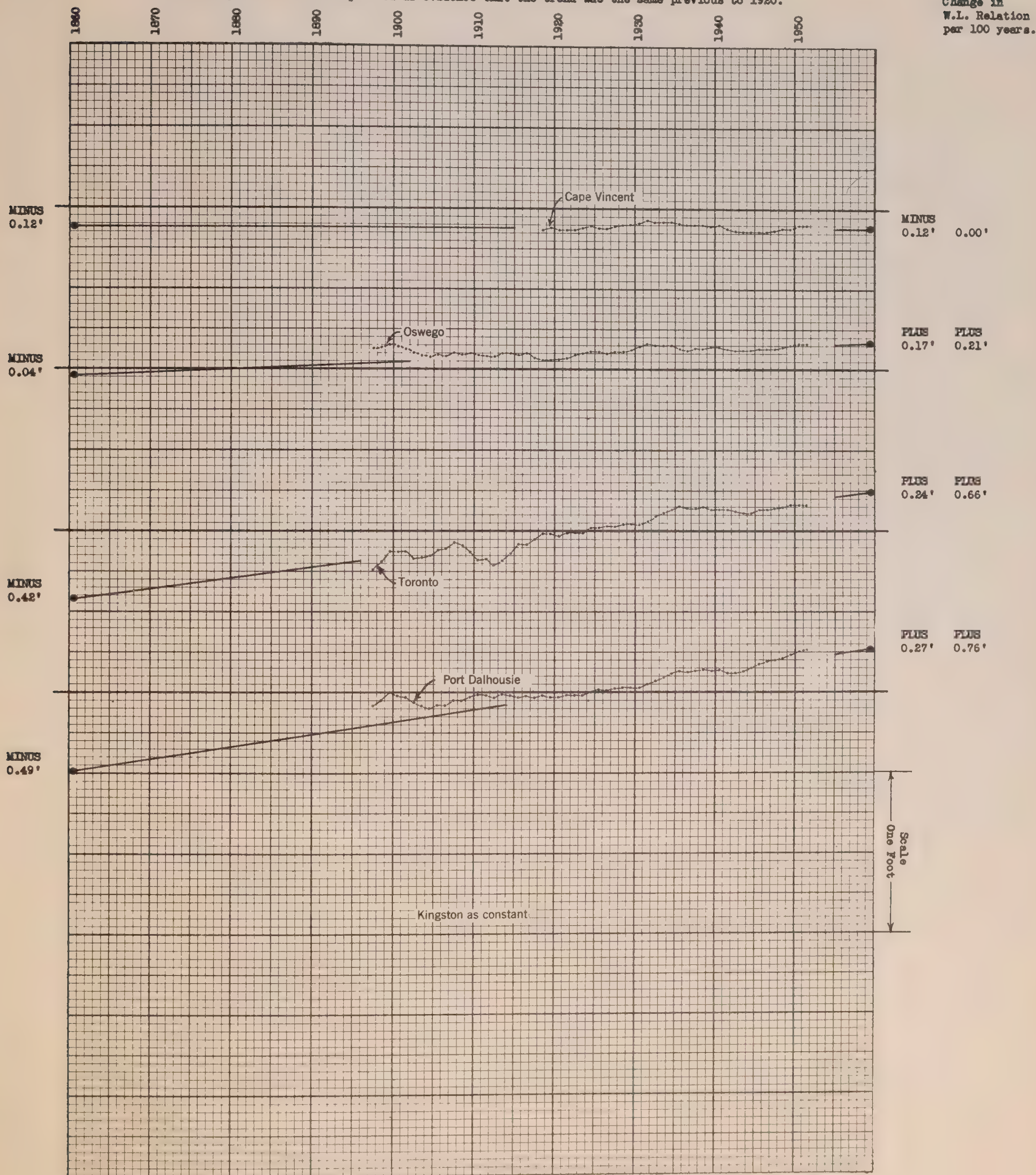
March 1954

LAKE ONTARIO

Moving five year mean water surface elevations for June-September, relative to the moving five year mean water surface elevations during the same period at Kingston, Ontario.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919.
The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



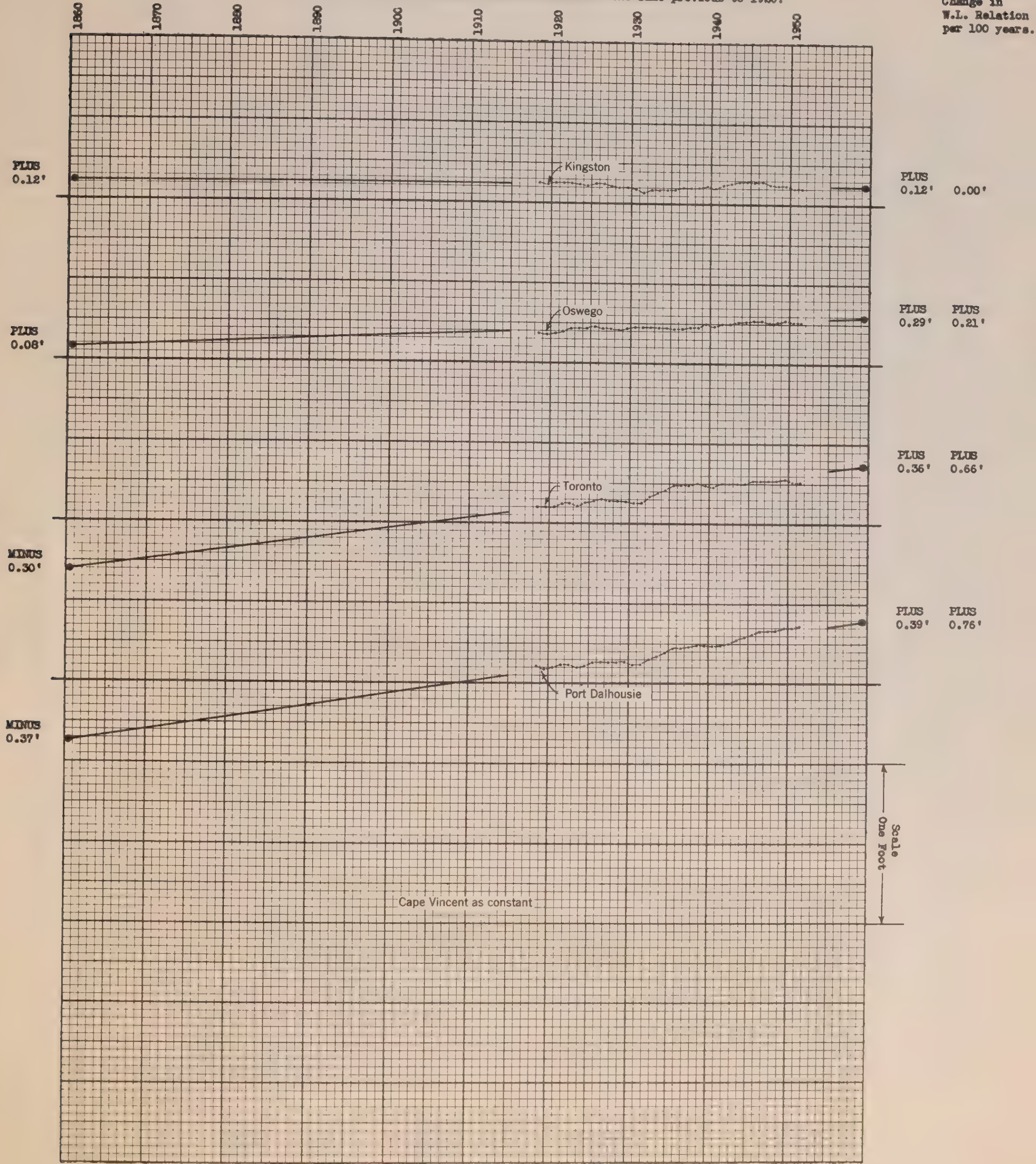
Canadian Hydrographic Service. Department of Mines and Technical Surveys, Ottawa, Canada. March 1954

LAKE ONTARIO

Moving five year mean water surface elevations for June-September, relative to the moving five year mean water surface elevations during the same period at Cape Vincent, New York.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919.
The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.   March 1954

LAKE ONTARIO

Recorded mean water surface elevations for June-September of each year, relative to the mean water surface elevations of the five locations during the same period.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919. The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.

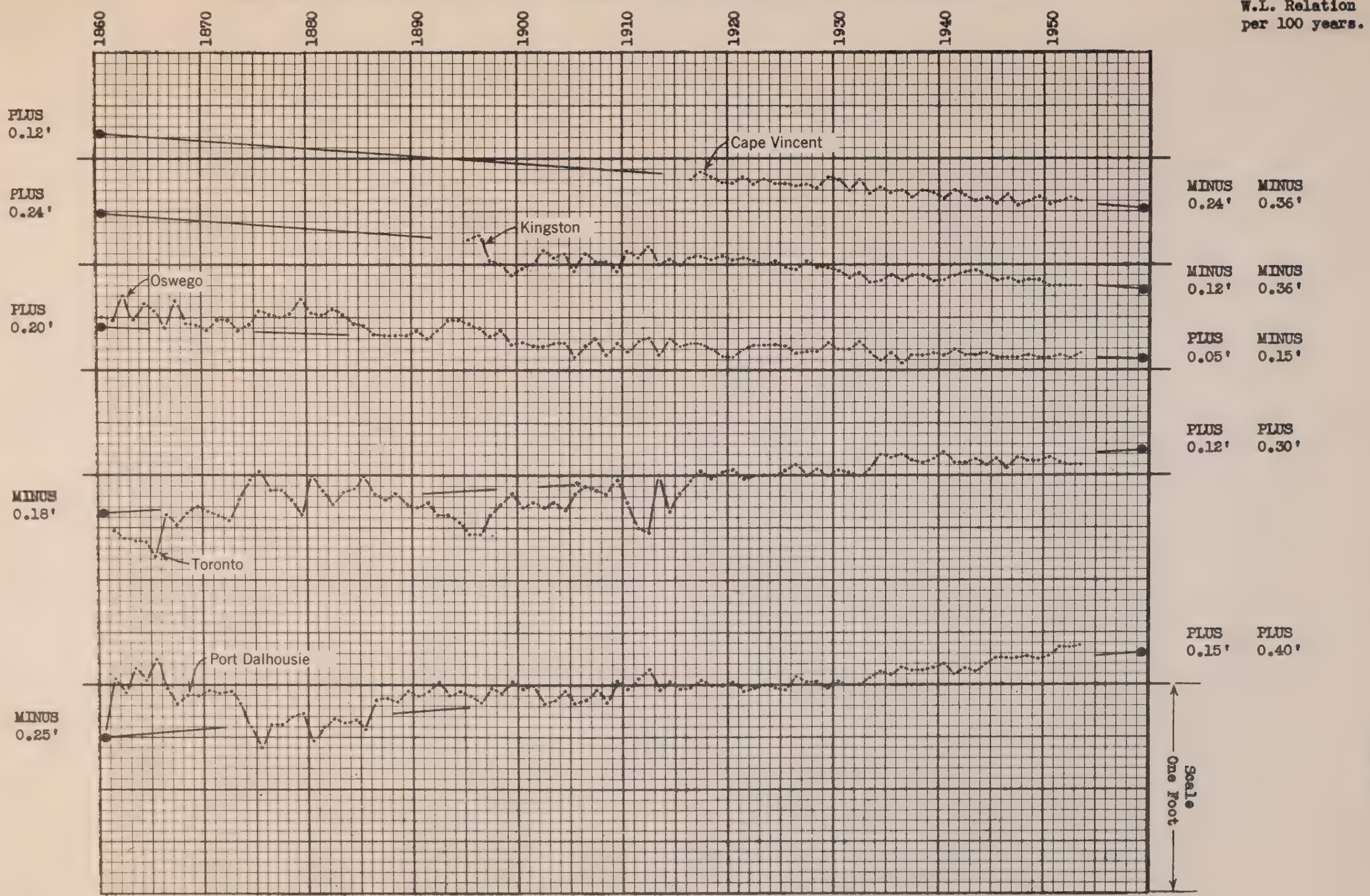


Plate No. 0 - 3

Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada. March 1954

LAKE ONTARIO

Moving five year mean water surface elevations for June-September, relative to the moving five year mean water surface elevations of the five locations during the same period.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

The average lines of change in relation, are based principally on the data since 1919.
The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.

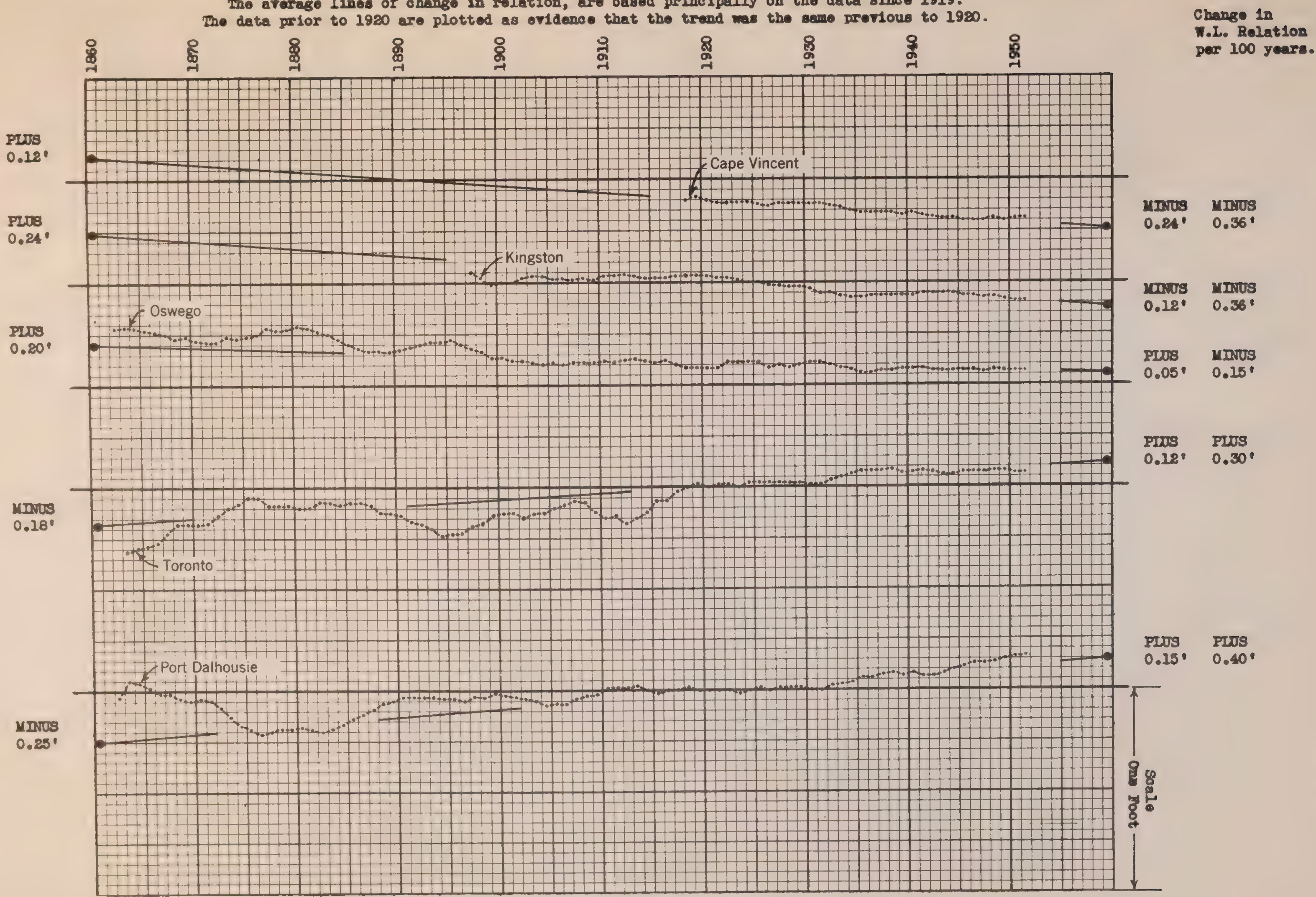


Plate No. 0 - 4

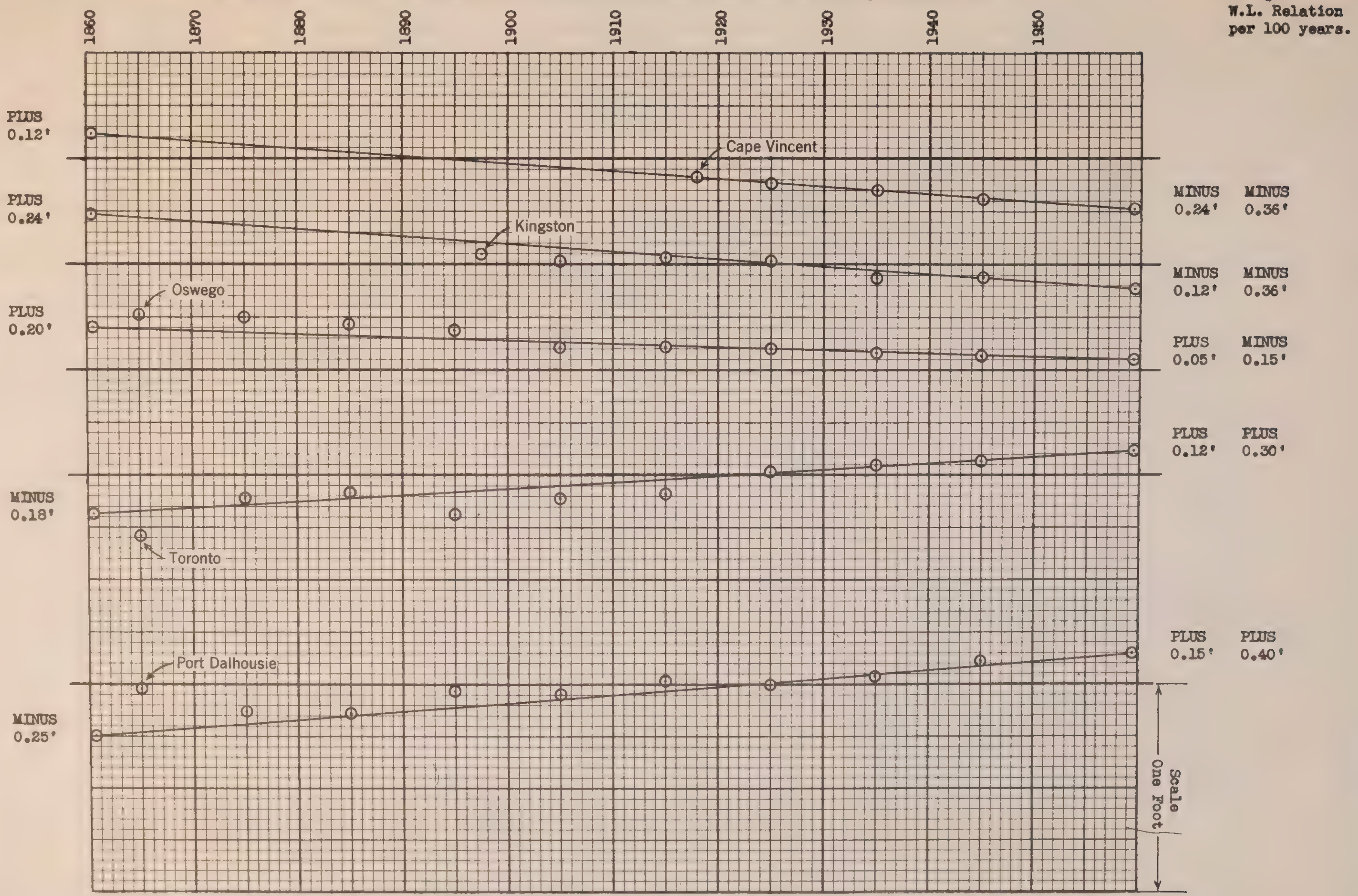
Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada. March 1954

LAKE ONTARIO

Ten year mean water surface elevations for June-September, relative to the ten year mean water surface elevations of the five locations during the same period.

The differential movement of the earth's crust is in the opposite direction to the apparent change in water level relation.

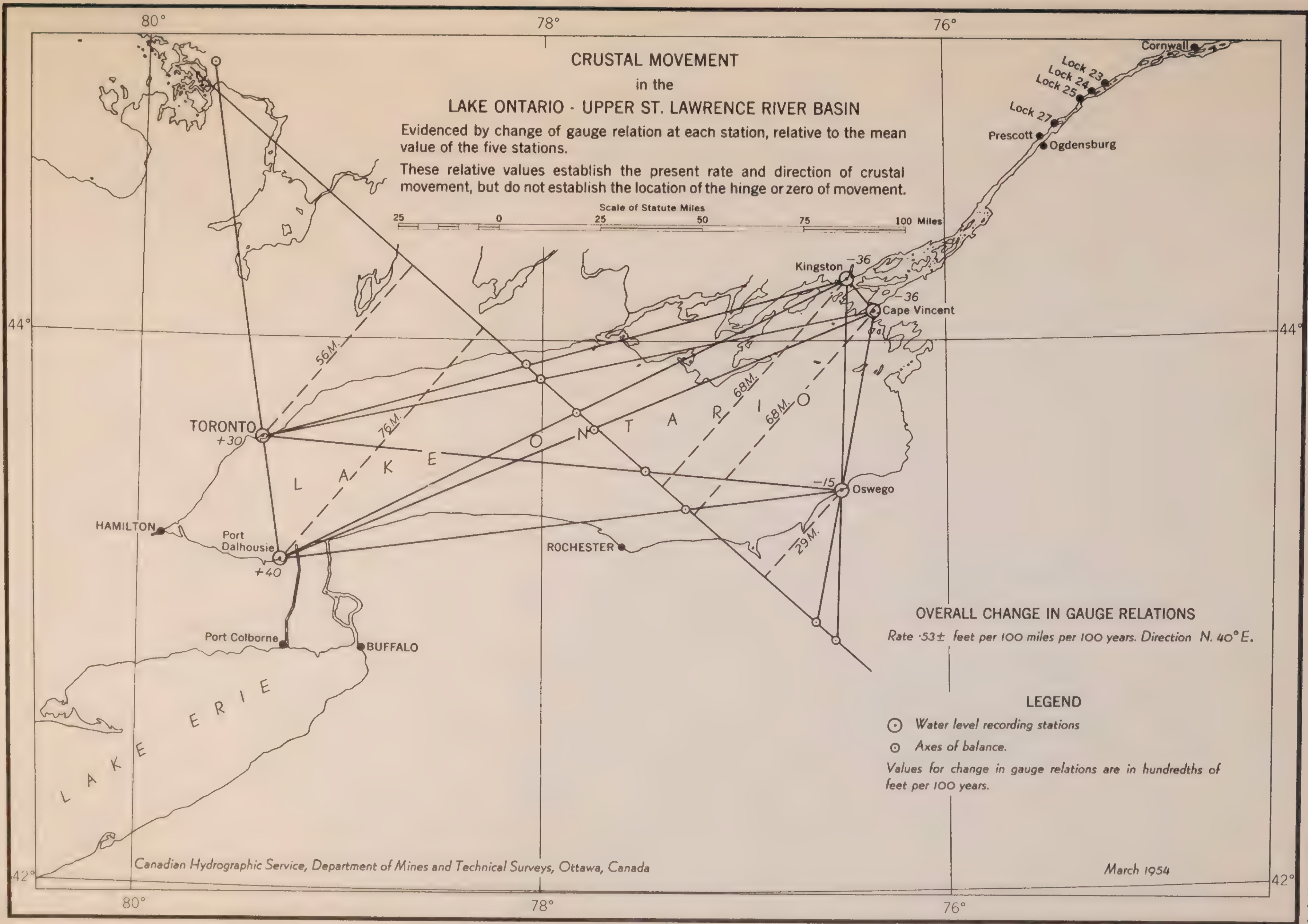
The average lines of change in relation, are based principally on the data since 1919. The data prior to 1920 are plotted as evidence that the trend was the same previous to 1920.



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada. March 1954

Plate No. 0 - 5

Plate No. 0-6



CRUSTAL MOVEMENT
in the
LAKE ONTARIO - UPPER ST. LAWRENCE RIVER BASIN
Evidenced by change of gauge relation at each station, relative to the mean value of the five stations.
These relative values establish the present rate and direction of crustal movement, but do not establish the location of the hinge or zero of movement.
Scale of Statute Miles
25 0 25 50 75 100 Miles
80°
78°
76°
44°
42°
Cornwall
Lock 23
Lock 24
Lock 25
Lock 27
Prescott
Ogdensburg
Kingston
−36
Cape Vincent
−36
Oswego
−15
TORONTO
+30
Port Dalhousie
+40
HAMILTON
ROCHESTER
Port Colborne
BUFFALO
LAKE ONTARIO
LAKE ERIE
56M.
76M.
68M.
68M.
29M.
OVERALL CHANGE IN GAUGE RELATIONS
Rate ·53± feet per 100 miles per 100 years. Direction N. 40° E.
LEGEND
Water level recording stations
Axes of balance.
Values for change in gauge relations are in hundredths of feet per 100 years.
Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada
March 1954

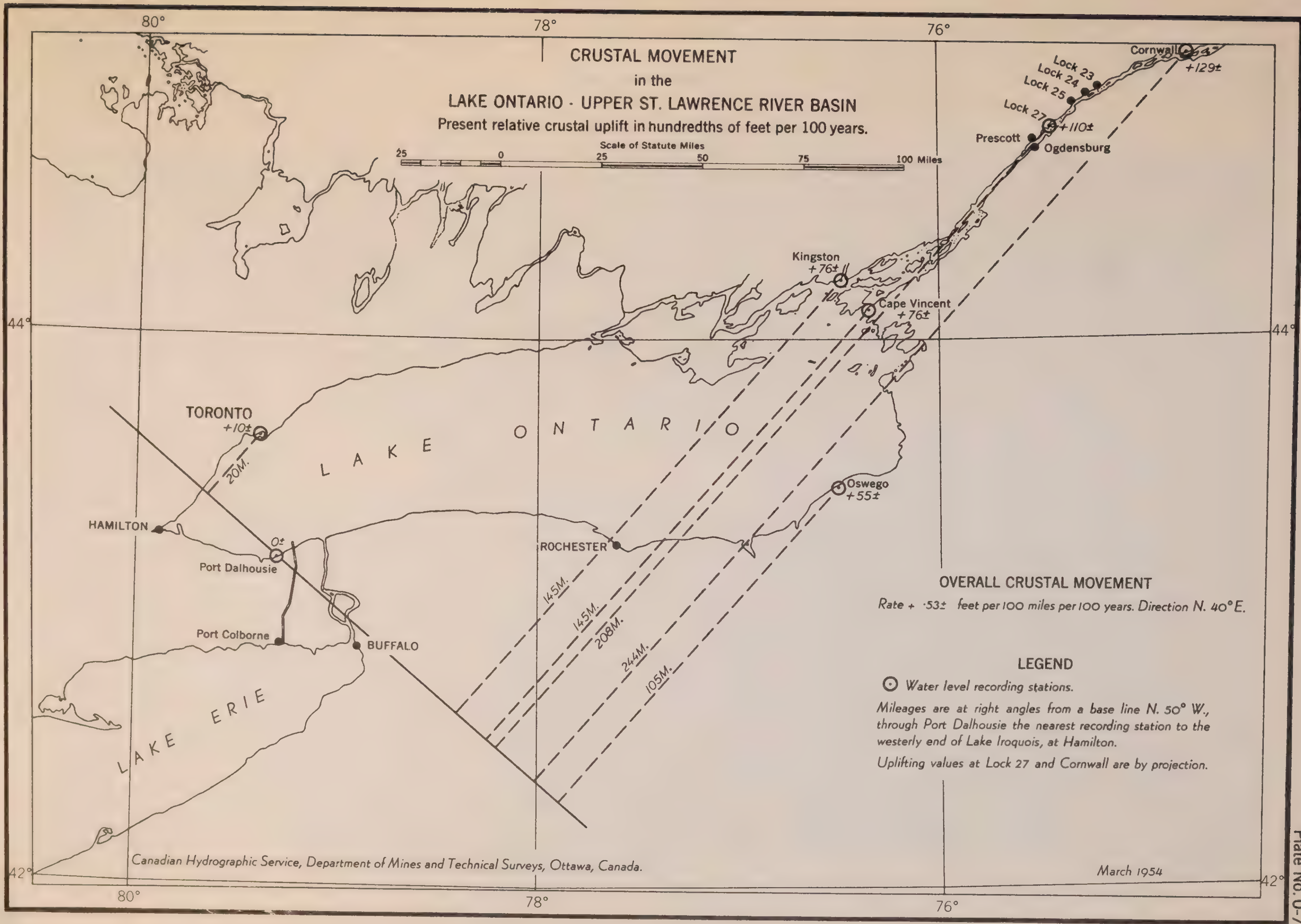
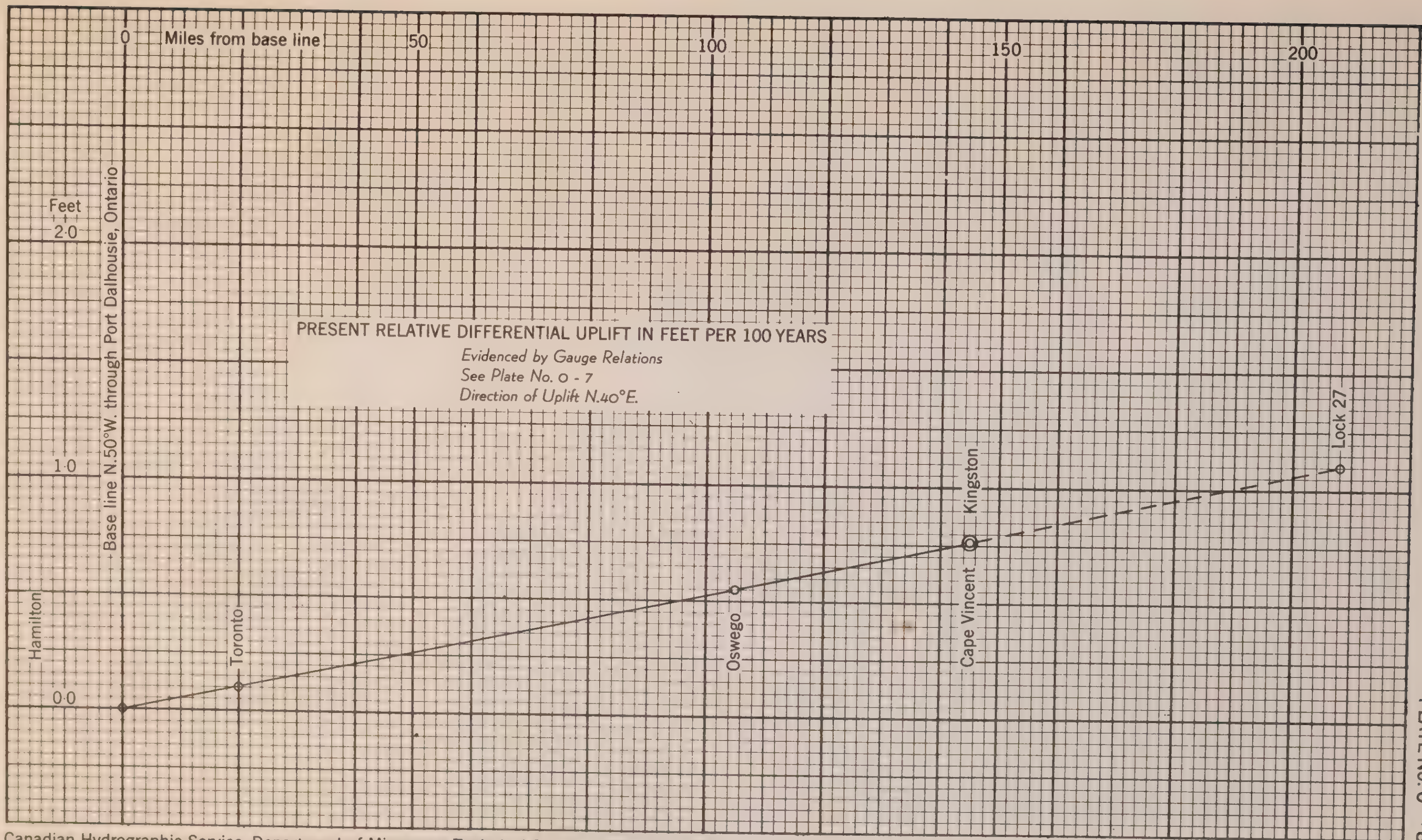

CRUSTAL MOVEMENT
in the
LAKE ONTARIO - UPPER ST. LAWRENCE RIVER BASIN
Present relative crustal uplift in hundredths of feet per 100 years.
Scale of Statute Miles
25
0
25
50
75
100 Miles
80°
78°
76°
44°
42°
Cornwall
+129±
Lock 23
Lock 24
Lock 25
Lock 27
+110±
Prescott
Ogdensburg
Kingston
+76±
Cape Vincent
+76±
TORONTO
+10±
20M.
LAKE ONTARIO
Oswego
+55±
HAMILTON
0±
Port Dalhousie
ROCHESTER
145M.
145M.
208M.
244M.
105M.
Port Colborne
BUFFALO
LAKE ERIE
OVERALL CRUSTAL MOVEMENT
Rate + ·53± feet per 100 miles per 100 years. Direction N. 40° E.
LEGEND
Water level recording stations.
Mileages are at right angles from a base line N. 50° W., through Port Dalhousie the nearest recording station to the westerly end of Lake Iroquois, at Hamilton.
Uplifting values at Lock 27 and Cornwall are by projection.
Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.
March 1954

PLATE No. 0 - 8

CRUSTAL MOVEMENT
in the
LAKE ONTARIO - UPPER ST. LAWRENCE RIVER BASIN



Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada,

March 1954

CRUSTAL MOVEMENT
in the
LAKE ONTARIO - UPPER ST. LAWRENCE RIVER BASIN

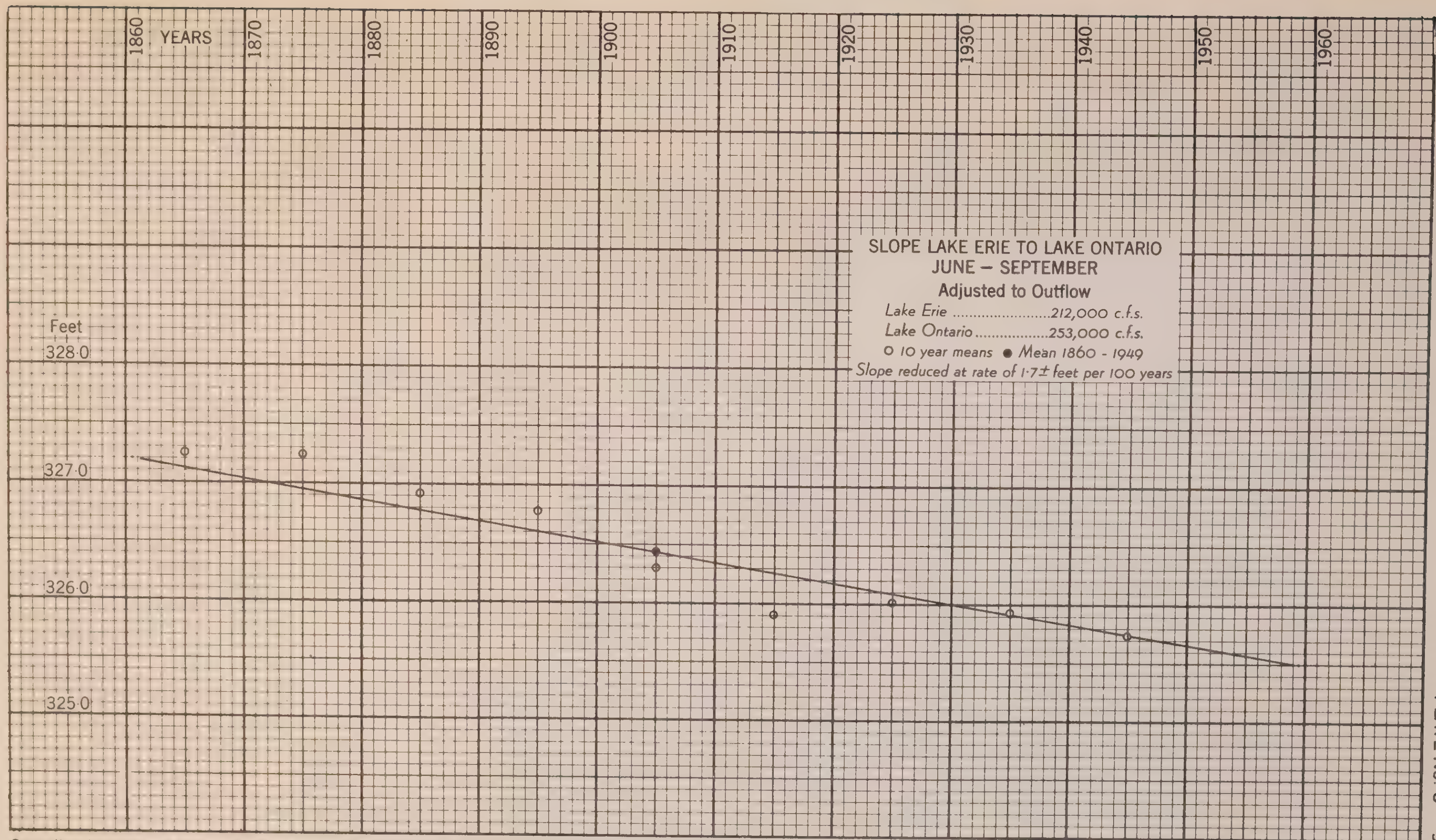


PLATE No. 0 – 9

Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada,

March 1954

CRUSTAL MOVEMENT
in the
LAKE ONTARIO - UPPER ST. LAWRENCE RIVER BASIN

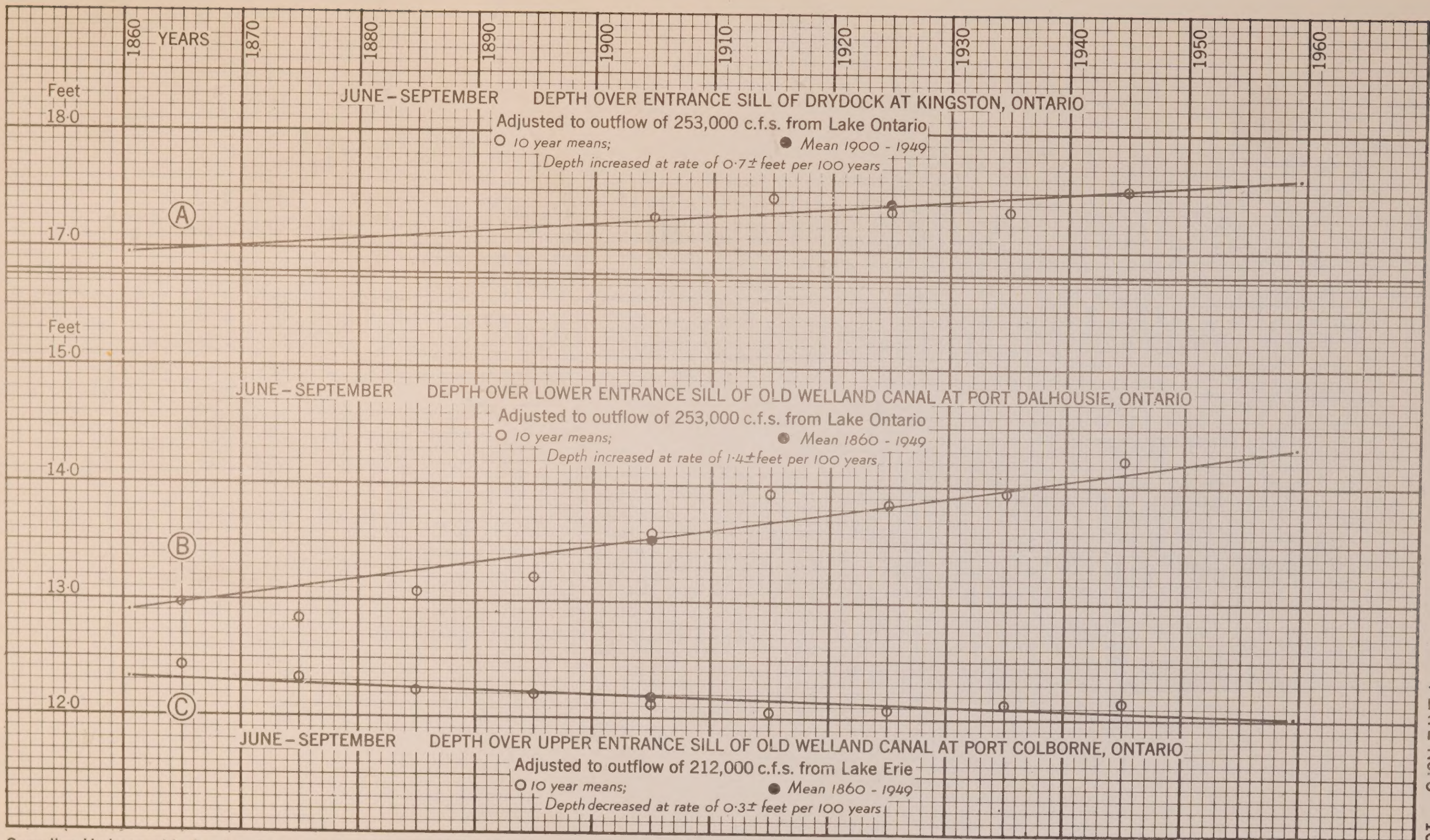


PLATE No. 0 - 10

Canadian Hydrographic Service, Department of Mines and Technical Surveys, Ottawa, Canada.

March 1954